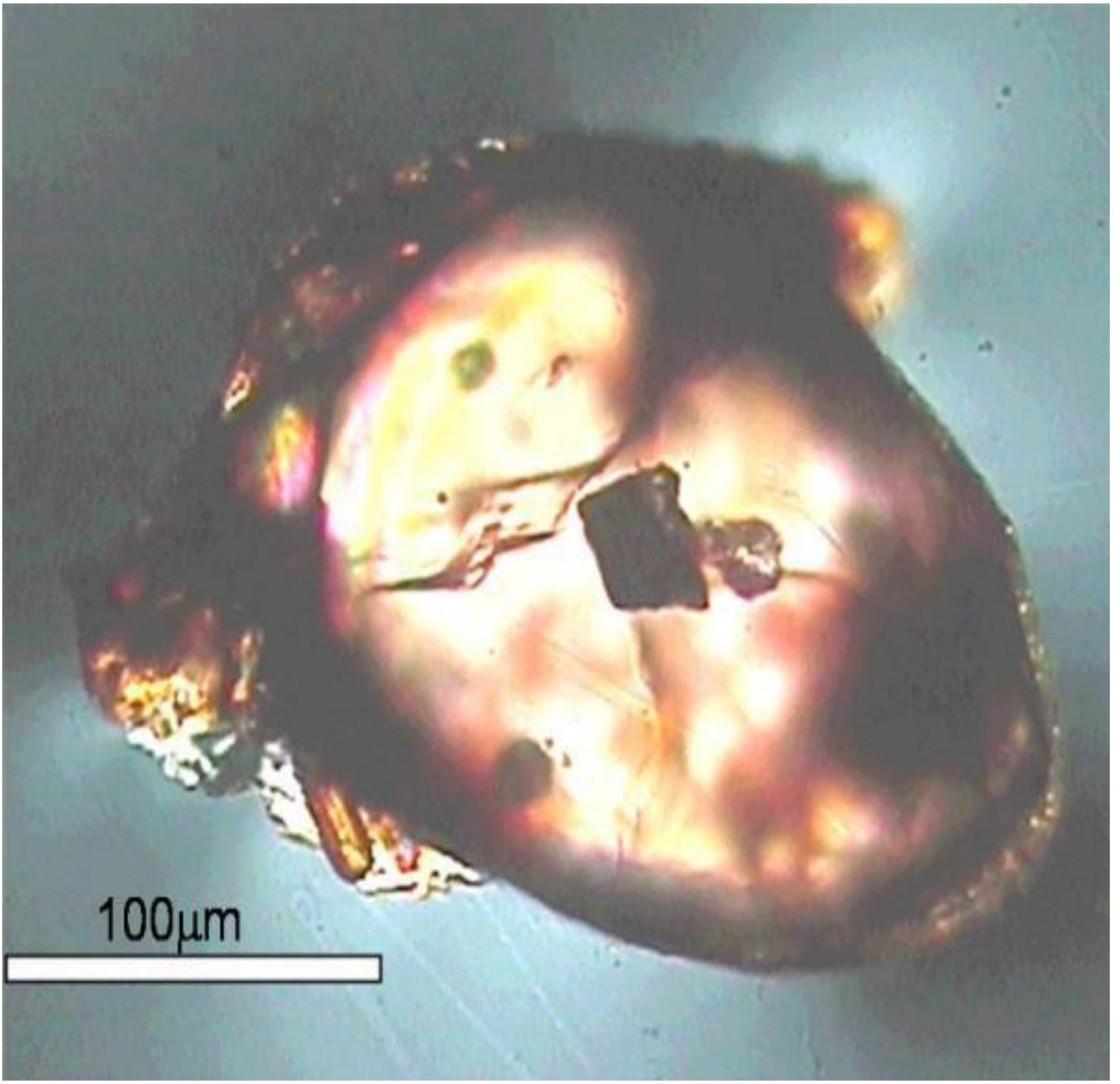


This tiny 4.4 billion-year-old mineral (called a zircon) is from the Jack Hills region of Western Australia. By analyzing the oxygen isotope ratios inside this zircon, one research team concluded that this zircon formed in a granite magma, and that the magma interacted with liquid water.

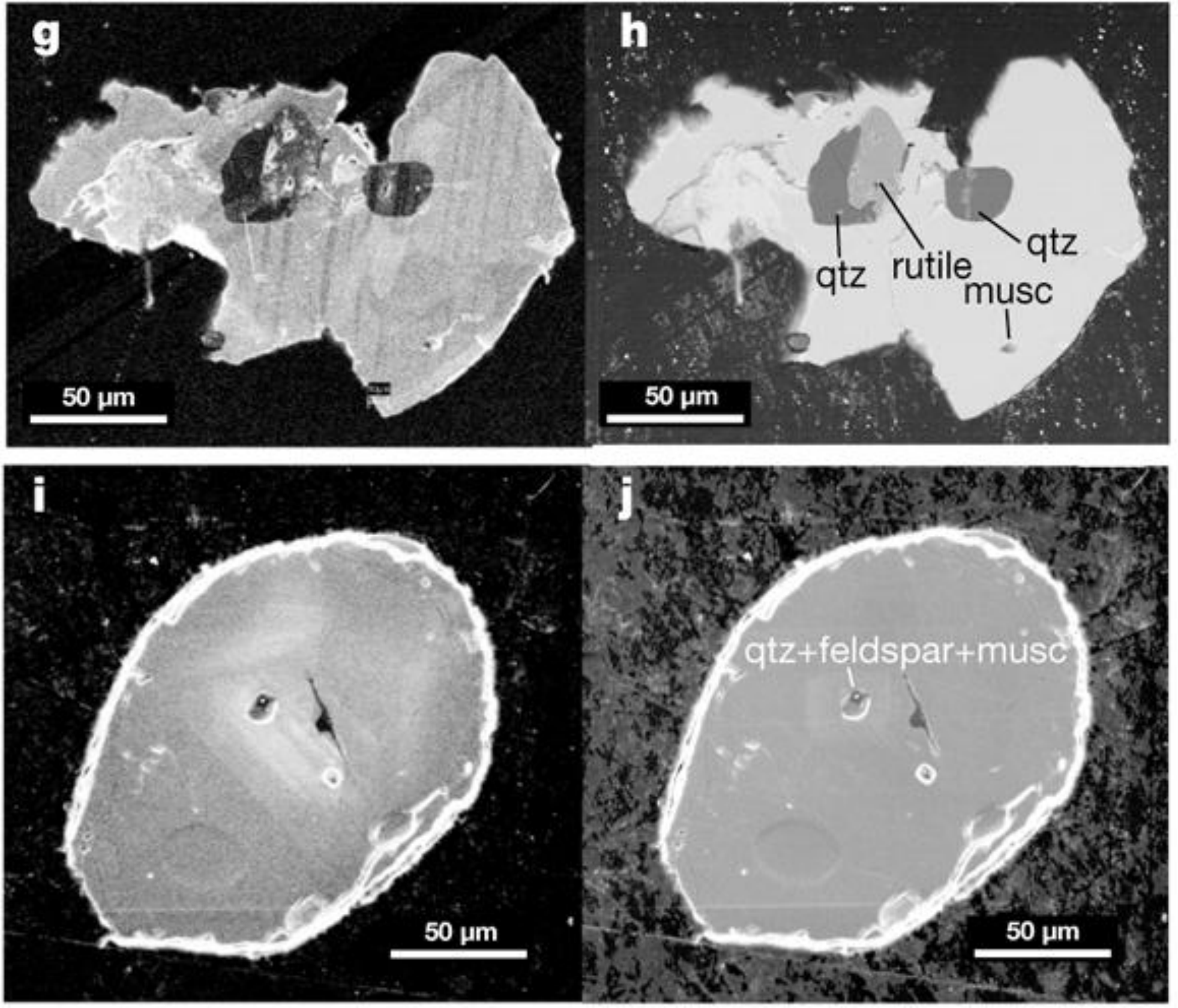
Note: This interpretation is still hotly contested within the scientific community.

Reference: Wilde, S. A.; et al. (2001). "Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago." (PDF). Nature 409 (6817): 175–178. doi:10.1038/35051550.

These rocks from the far northeastern part of Canada were radiometrically age-dated at 4.28 billion years old, which, if true, would make them the oldest Earth rocks ever found. (Rocks are accumulations of minerals – zircon would be a mineral, not a rock).

Note: This interpretation is still hotly contested within the scientific community. The researchers who did the analysis used new and unusual dating methods. They have not yet been verified.

Reference: O'Neil, Jonathan et al. (2008) Neodymium-142 Evidence for Hadean Mafic Crust. Science 26: DOI: 10.1126/science.1161925



These tiny 4.19 billion-year-old zircon are from the Jack Hills region of Western Australia. By analyzing even tinier minerals trapped inside them, one team of researchers constrained the temperature and pressures under which the zircons could have formed. They found that the temperatures and pressures were very similar to those found above subduction zones on modern earth. They interpret this as evidence of subduction – and therefore, plate tectonics – on early Earth.

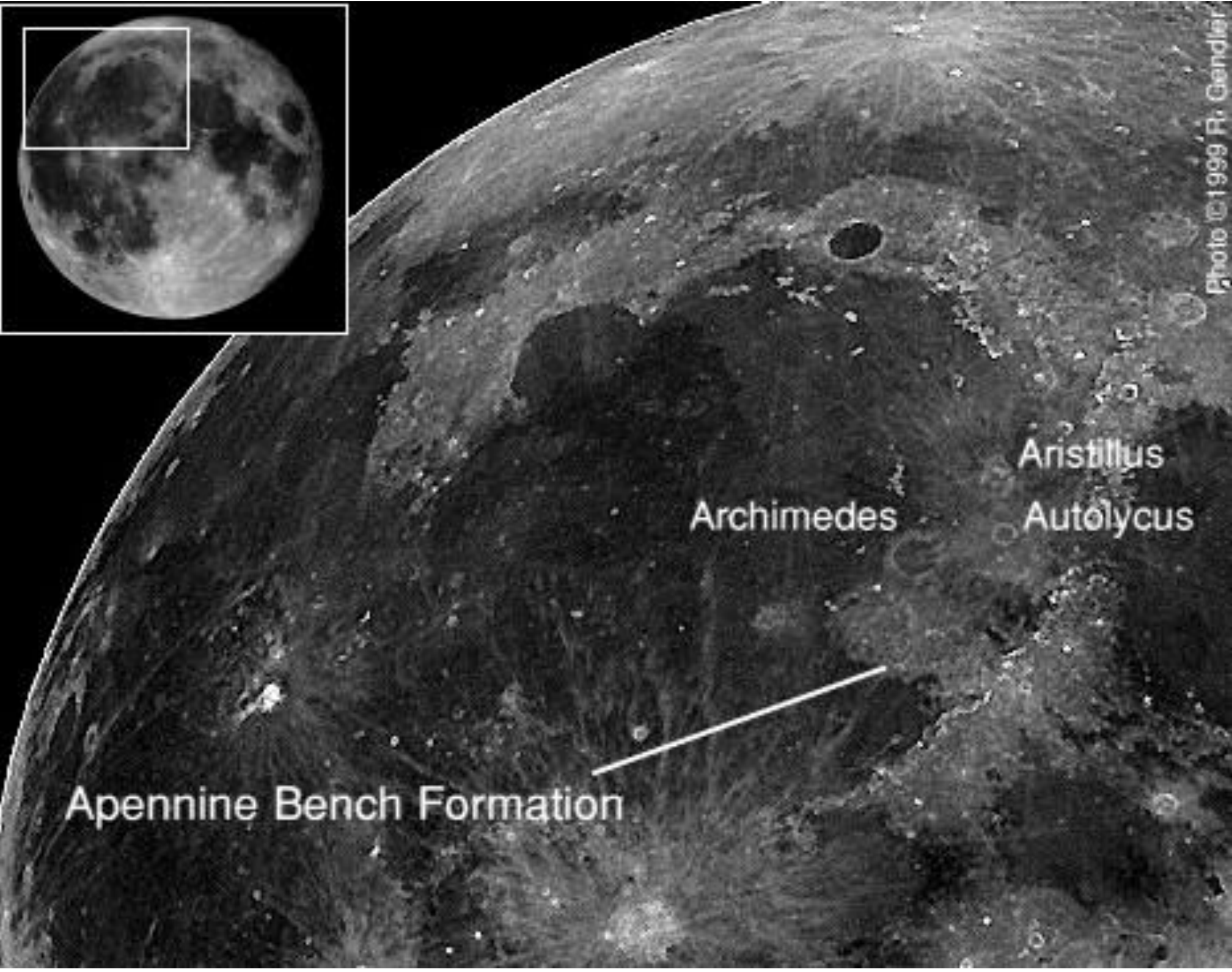
Note: This interpretation is still contested within the scientific community.

Reference: Hopkins, M. et al. (2008) Low heat flow inferred from >4 Gyr zircons suggests Hadean plate boundary interactions. Nature 456: doi:10.1038/nature07465.

These rocks – called the Acasta Gneiss - from the far northeastern part of Canada were radiometrically age-dated at 4.01 billion years old.

Note: This interpretation is generally accepted by the scientific community.

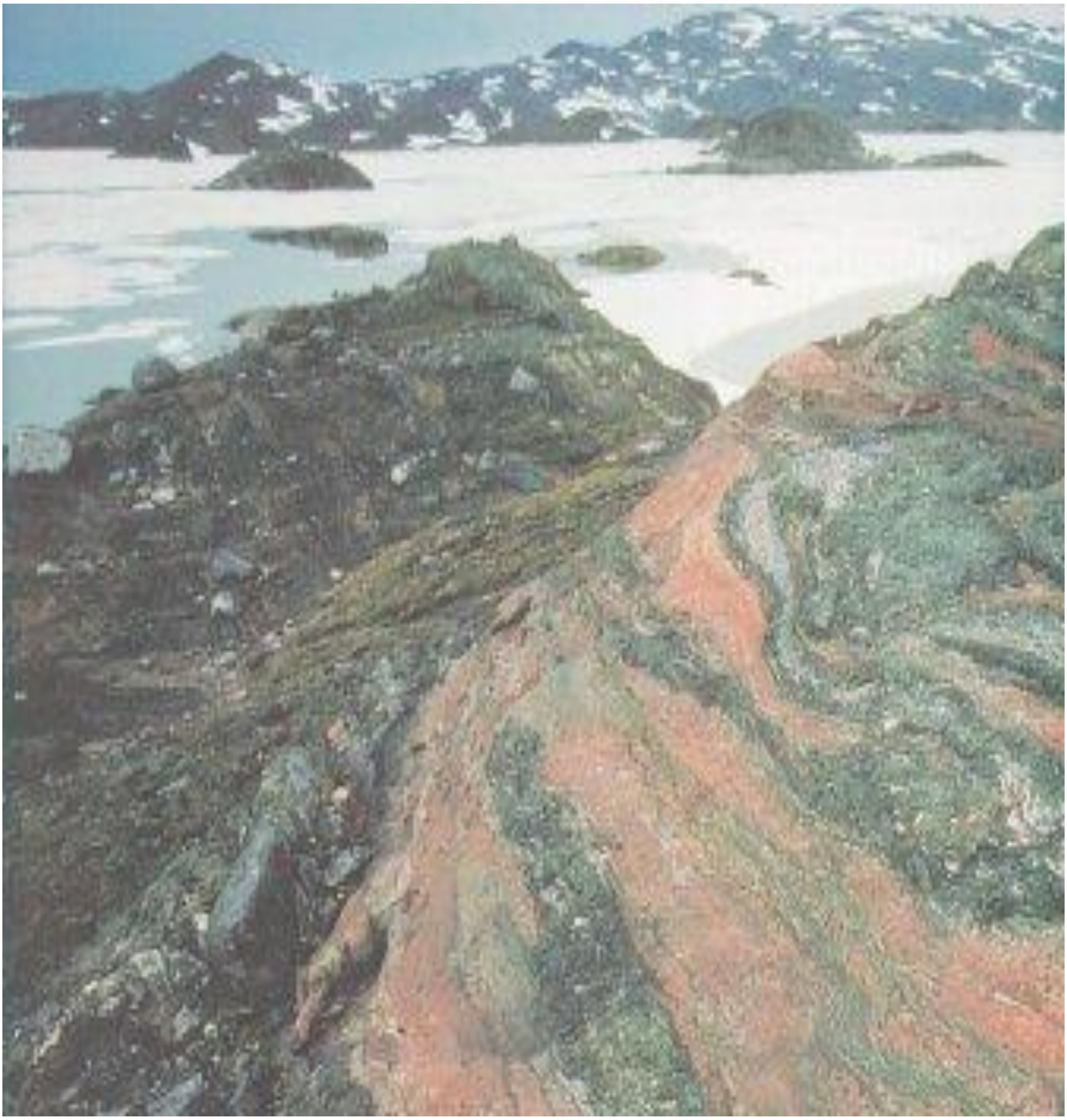
Reference: Bowring, S. et al.. (1999) Priscoan (4.00-4.03 Ga) orthogneisses from northwestern Canada. CONTRIBUTIONS TO MINERALOGY AND PETROLOGY 134: 3-16 .



The Apollo astronauts brought back rocks from the Moon. Researchers back on Earth found that the rocks had lots of impact melt (rock that melted when struck by an asteroid). They radiometrically dated the melt and found that all of samples were 4.1 to 3.8 billion years old. From this, it looks like the majority of craters on the Moon formed during that time, which they named Late Heavy Bombardment.

Researchers concluded that Moon experienced a huge influx of asteroids and comets during this period of time – presumably, the Earth did too. It is estimated that these impacts were so large that they could have vaporized all Earth's oceans, remelted its entire crust, and dispersed its atmosphere during this time.

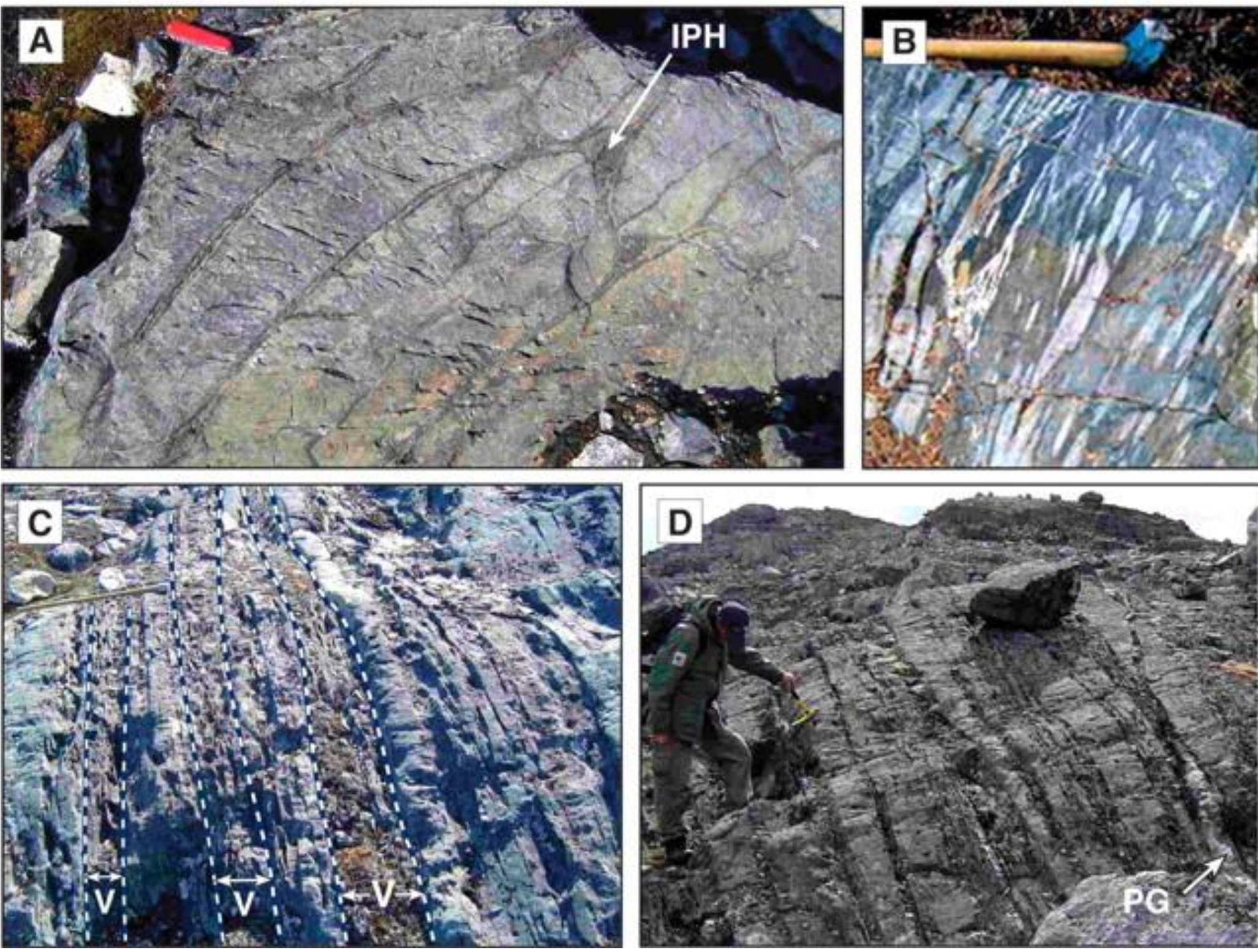
Note: This interpretation is generally accepted by the scientific community.



These rocks from Greenland were radiometrically age-dated at 3.8 billion years old. Researchers have measured the rock's oxygen isotope ratio, which can show what kind of environment the rock formed in. They've concluded that the climate was hot when this rock formed – perhaps 50˚C.

Note: Some researchers debate whether oxygen isotope ratios can really be used to deduce climate conditions.

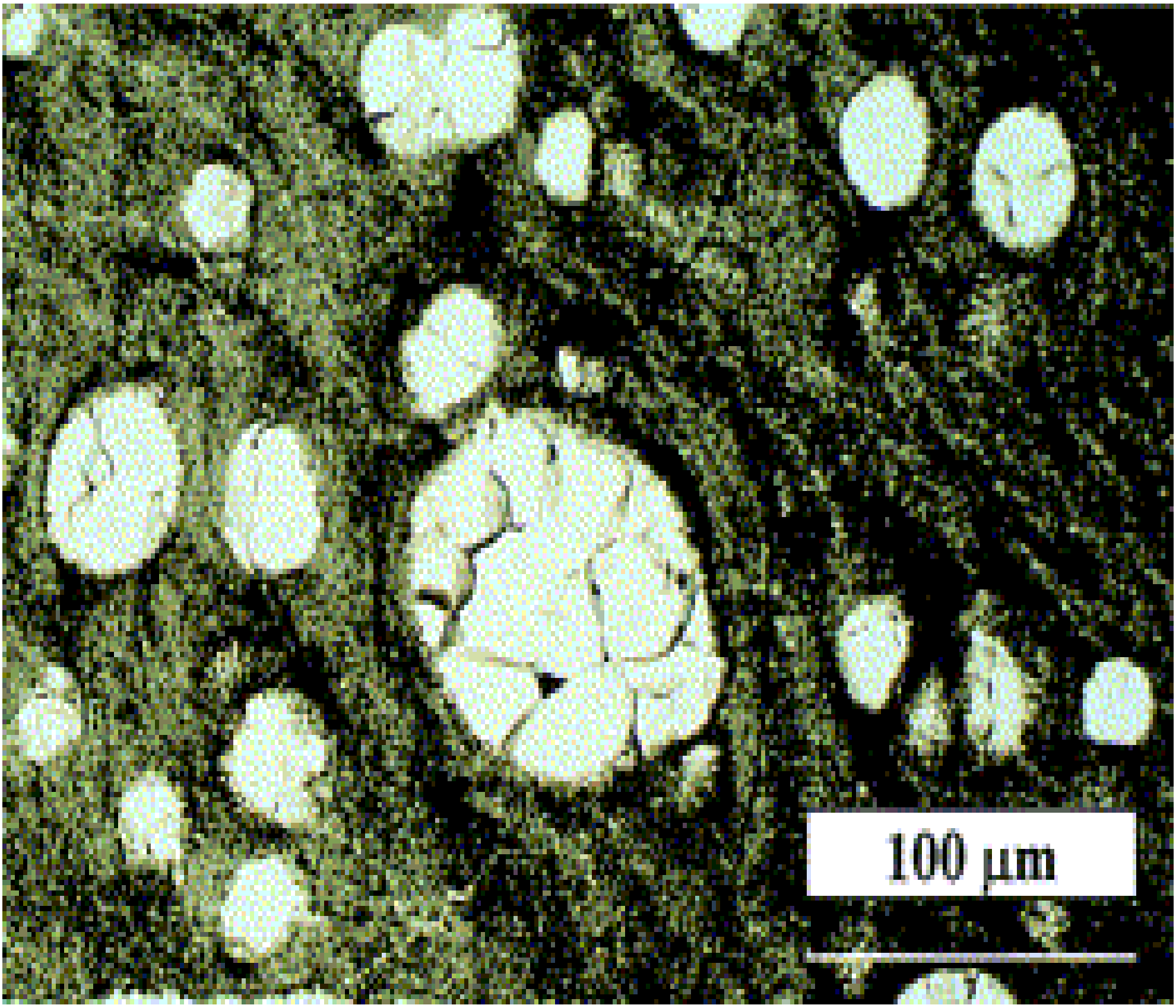
Reference: Kasting, James (2006) " Atmospheric composition and climate on the early Earth." Phil. Trans. R. Soc. B (2006) (361): 1733–1742. doi:10.1098/rstb.2006.1902.



These rocks from the Isua region of Greenland were radiometrically age-dated at 3.8 billion years old. Research interpret some of the rounded structures to be “pillow basalt”: a basalt structure that forms when basaltic lava erupts into water. On modern Earth, this occurs mostly at mid-ocean spreading centers that drive plate tectonics.

Note: Some researchers disagree with the interpretation that these structures are pillow basalts.

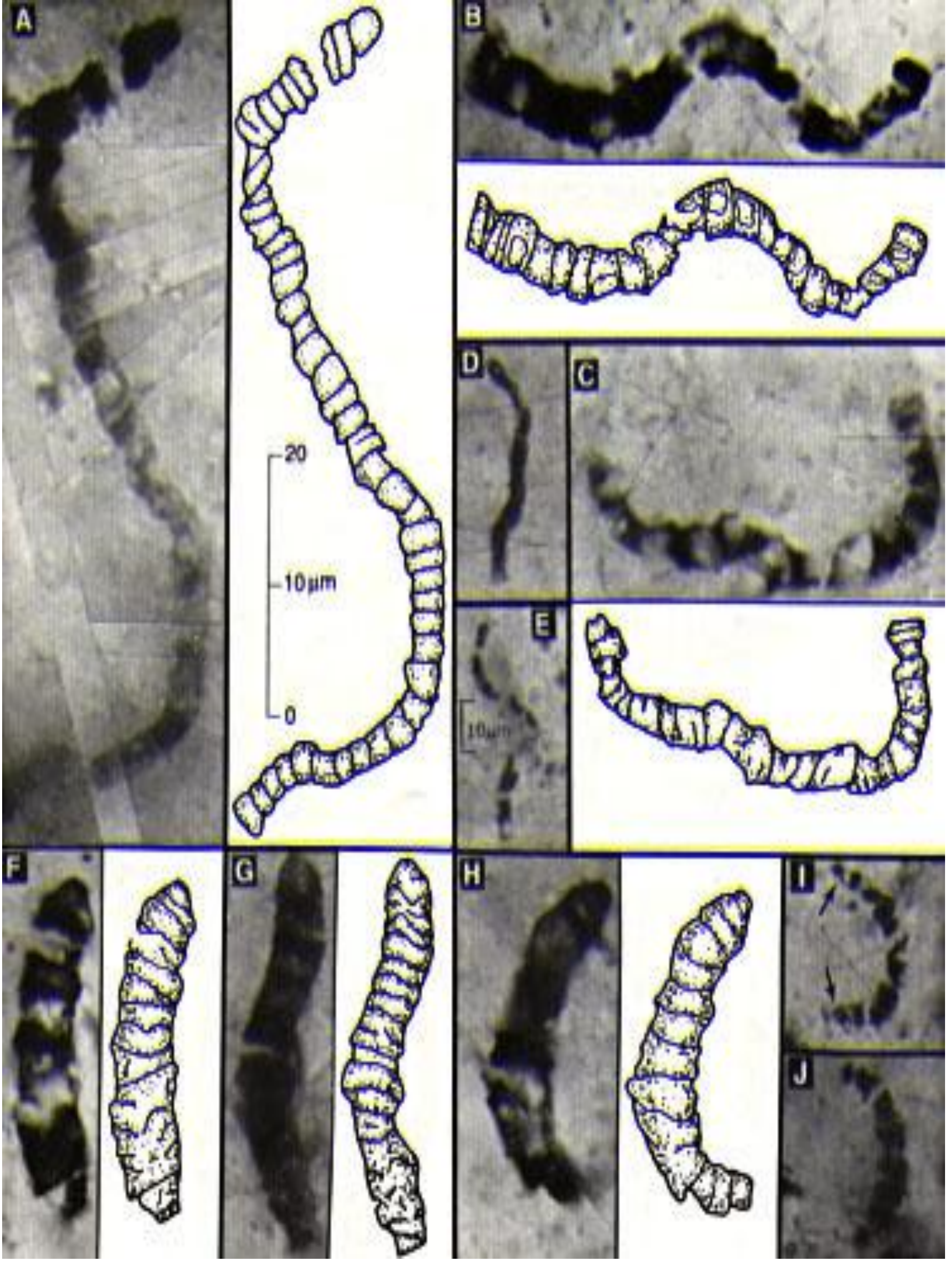
Reference: Furnes et al. (2007) A vestige of Earth’s oldest ophiolite. Science 315: DOI: 10.1126/science.1139170



These basaltic rocks from Greenland were radiometrically age-dated at 3.75 billion years old. They contain small globules and veins of quartz that some researchers interpret as evidence of a hydrothermal vent system

Note: There is no consensus among researchers on how these quartz globules formed. The hydrothermal vent scenario is one hypothesis.

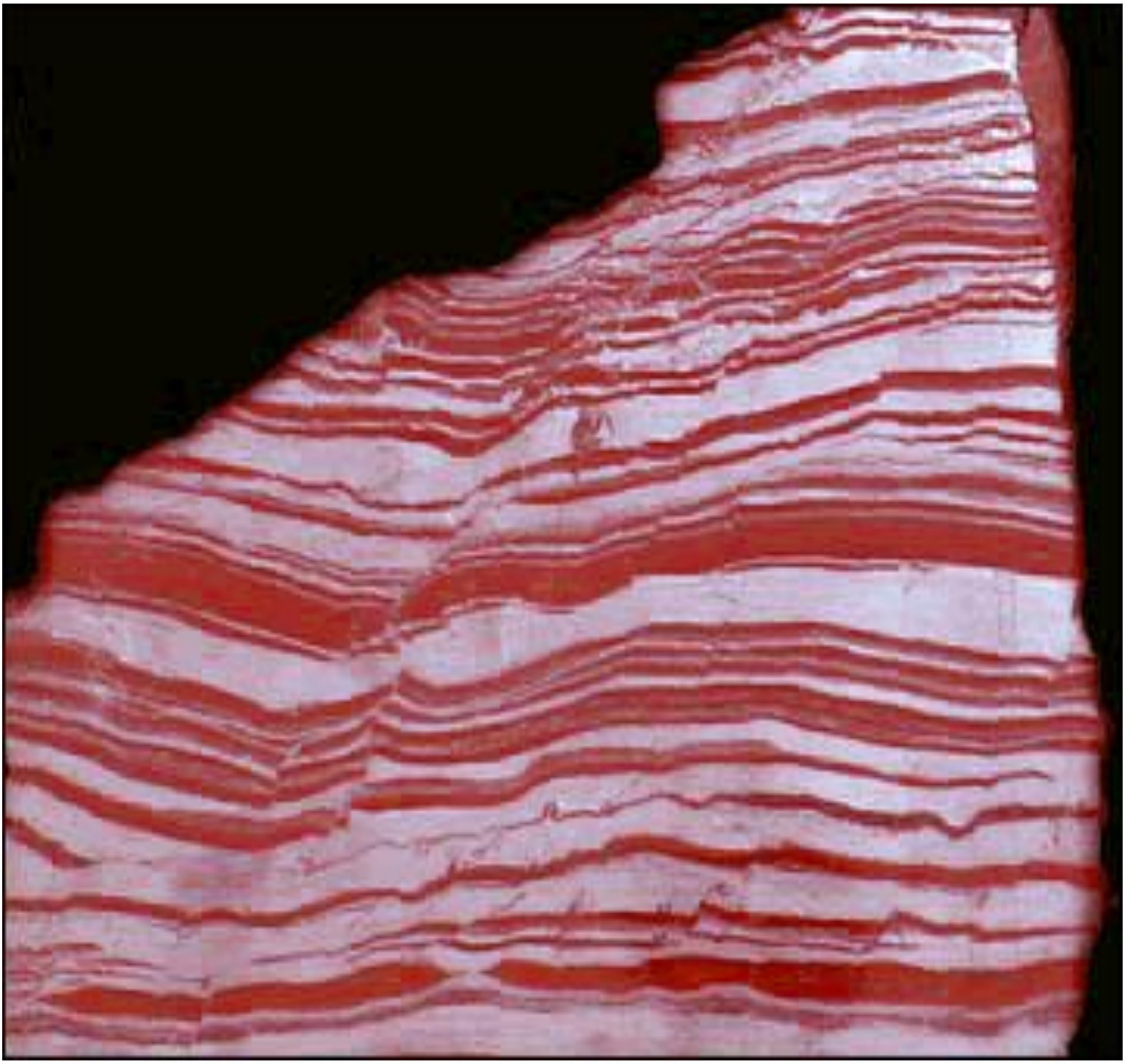
Reference: Appel, Peter W.U., Hugh R. Rollinson, and Jacques L.R. Touret. (2001) "Remnants of an Early Archaean (>3.75 Ga) sea-floor, hydrothermal system in the Isua Greenstone Belt." Precambrian Research, Vol. 112, Issues 1-2, 15 November, pp. 27–49



These structures were found in the 3.5-billion-year-old Apex Chert of Western Australia. Some researchers think the structures are fossilized microbes. Others think they are naturally-occurring mineral structures.

Note: This is an ongoing debate within the scientific community. There does not appear to be a consensus yet on whether these really are microfossils.

Reference: Schopf, William (1993) Microfossils of the Early Archean Apex Chert: New Evidence of the Antiquity of Life . Science 260: DOI: 10.1126/science.260.5108.640



These Greenland rocks – called the Isua Banded Iron Formation – were radiometrically age-dated at 3.5 billion years old. Banded Iron Formations are sedimentary rocks: iron-rich sediments laid down in deep water.

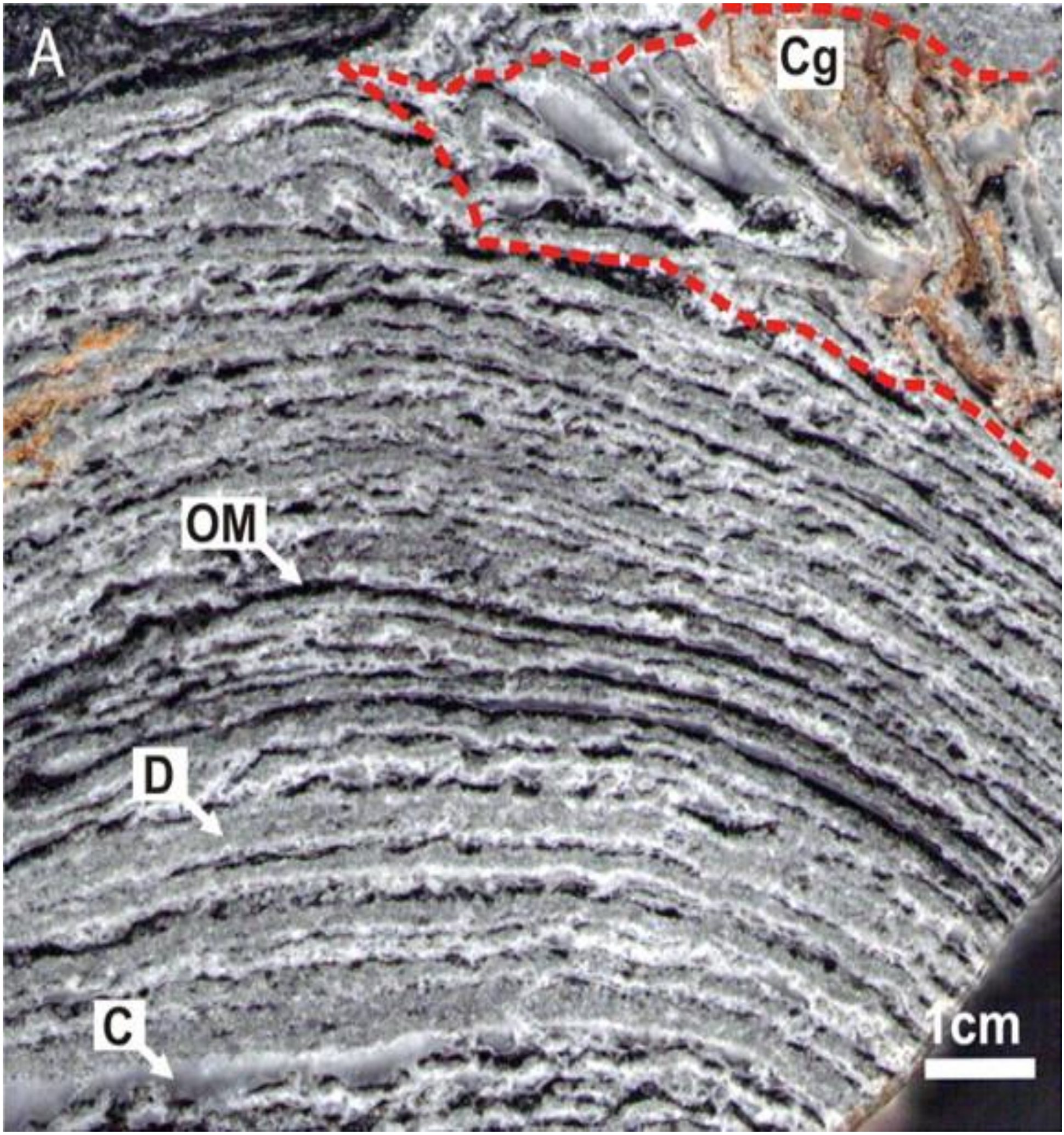
Note: This interpretation is generally accepted by the scientific community.

Reference: Bowring, S. et al.. (1999) Priscoan (4.00-4.03 Ga) orthogneisses from northwestern Canada. CONTRIBUTIONS TO MINERALOGY AND PETROLOGY 134: 3-16 .

This chert from the Pilbara part of Western Australia is 3.5 billion years old. One research team analyzed bubbles of water that had been trapped when the rock formed. In the bubbles, they found methane (CH4) with carbon isotope ratios that suggest it was created by methanogens: a type of bacteria that emits methane as a by-product instead of oxygen.

Note: This interpretation is still debated by the scientific community.

Reference: Ueno et al. (2006) Evidence from fluid inclusions for microbial methanogenesis in the early Archaean era. Nature 440: doi:10.1038/nature04584



This 3.45 billion-year-old rock is from Western Australia. Several research teams have interpreted the layers here as ancient **stromatolites.**

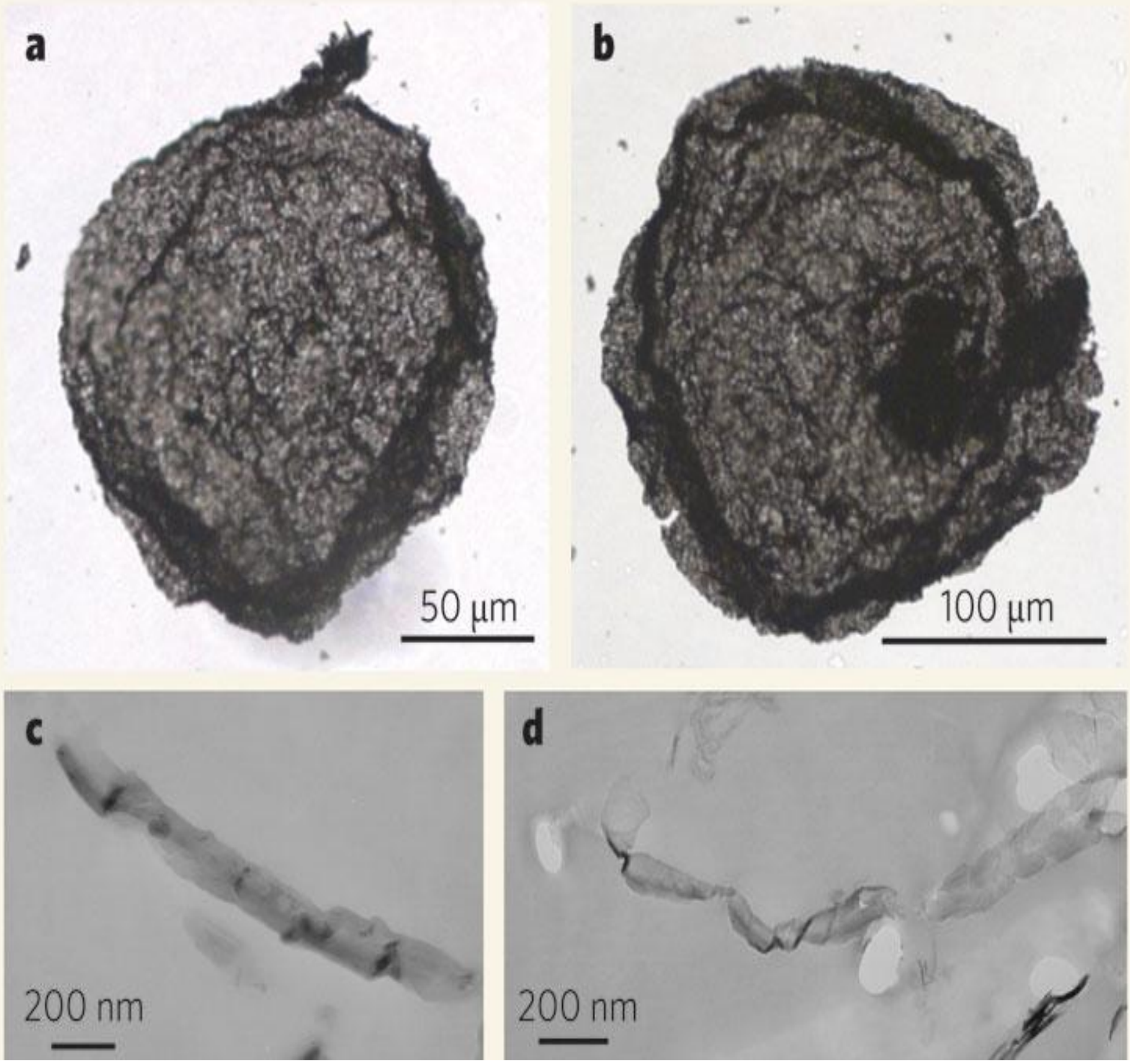
Note: This interpretation is still contested within the scientific community.

Reference: Allwood, Abigail; Grotzinger, Knoll, Burch, Anderson, Coleman, and Kanik (2009). "Controls on development and diversity of Early Archean stromatolites". *Proceedings of the National Academy of Sciences*.

This 3.3 billion-year-old rock is from the Barberton Cherts of South Africa. One research team examined oxygen isotope ratios in this rock, and concluded that the water that the chert formed in was very warm – perhaps 55–85 °C.

Note: This interpretation is still debated within the scientific community.

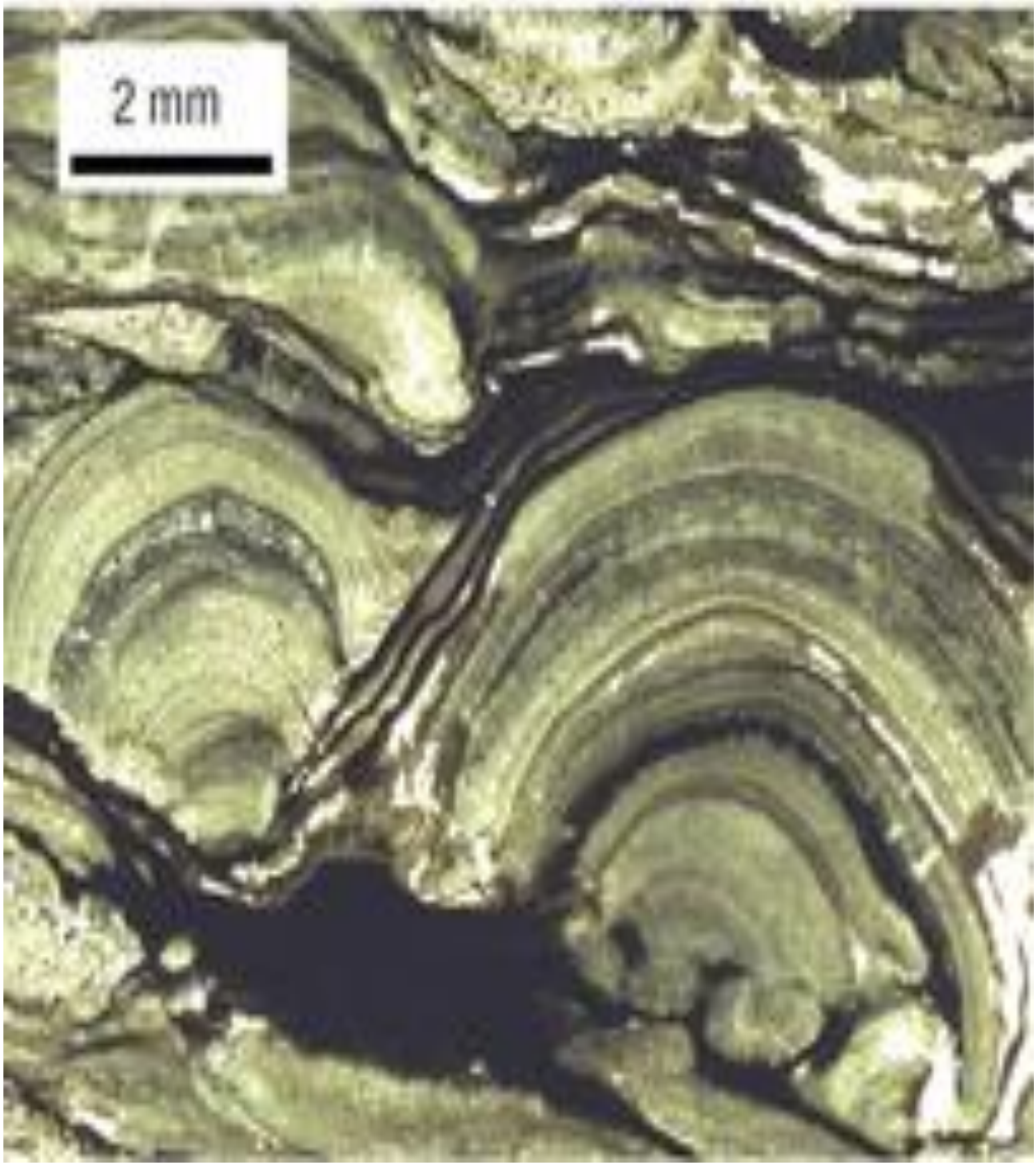
Reference: Knauth and Lowe (2003) High Archean climatic temperature inferred from oxygen isotope geochemistry of cherts in the 3.5 Ga Swaziland Supergroup, South Africa . GSA Bulletin, doi: 10.1130/0016-7606(2003)



These structures were found in 3.2-billion-year-old rocks from South Africa. They are interpreted to be acritarchs – presumably eukaryote cells.

Note: This paper was just released a few months ago, but I have no doubt there will be <u>much</u> debating – regard it as yet uncertain.

Reference: Javaux et al. (2010) Organic-walled microfossils in 3.2-billion-year-old shallow-marine siliciclastic deposits. Nature 463: doi:10.1038/nature08793



This 2.72 billion-year-old rock is from Western Australia. Several research teams have interpreted the layers here as ancient **stromatolites:** colonies of cyanobacteria.

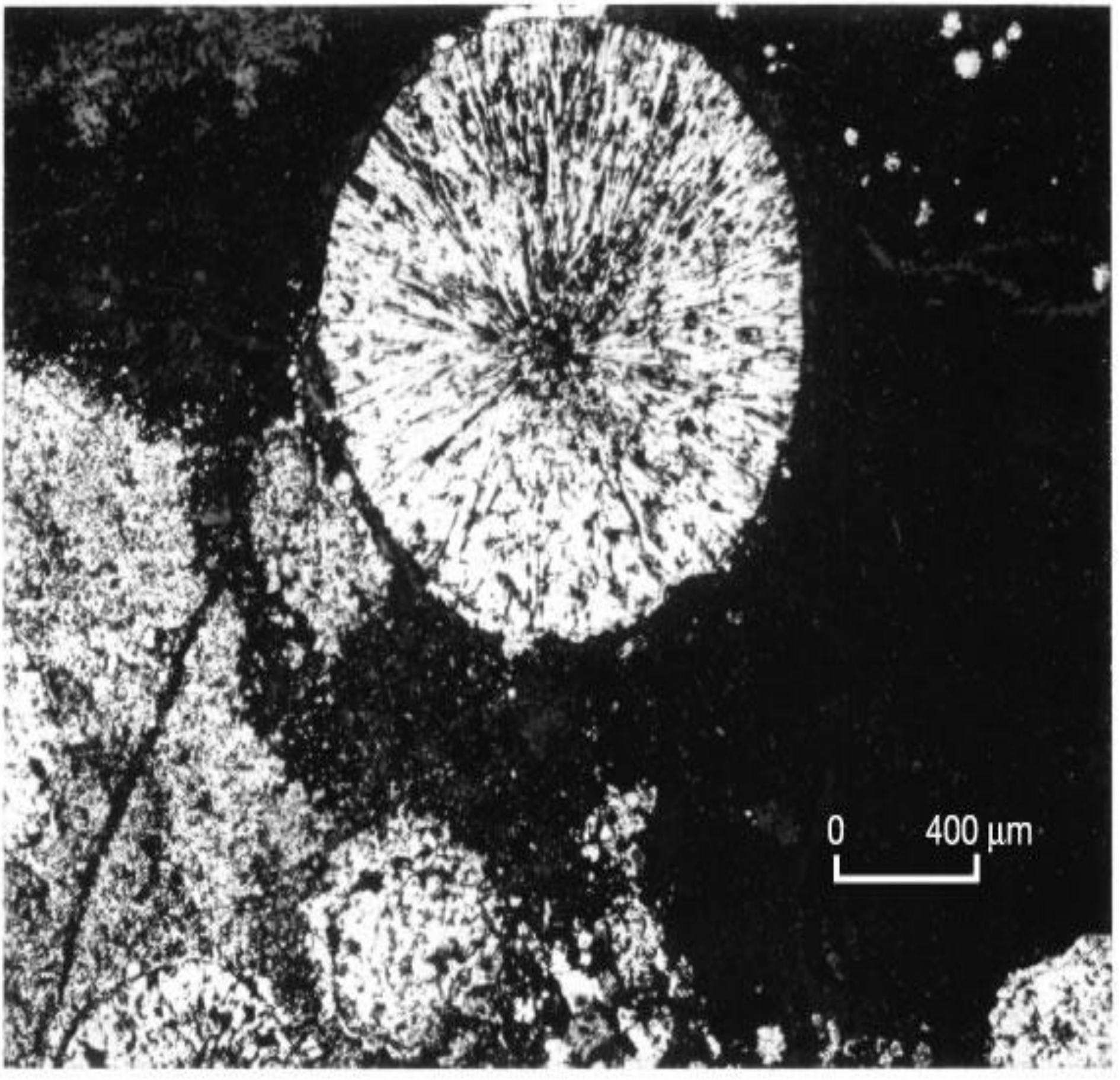
Note: This interpretation is generally accepted by the scientific community

Reference: Lepot, Kevin; Karim Benzerara, Gordon E. Brown, Pascal Philippot (2008). "Microbially influenced formation of 2.7 billion-year-old stromatolites". Nature Geoscience 1: 118–21. doi:10.1038/ngeo107.

Which gases are given off by a volcano depends on the composition of the magma. Specifically, it depends on the "redox state." A "reducing" magma produces one set of minerals – and gives off gases like CH_4 and NH_3 (methane and ammonia). An "oxidized" magma fugacity produces modern volcanic gases – CO_2, SO_2, etc.

This rock is a 2.7-billion-year-old komatiite (a type of ancient igneous rock). One research team analyzed the "redox state" of this rock by examining the ratio of iron atoms with 24 electrons to iron atoms with 23 electrons. They concluded that the magma that formed this rock was reducing.

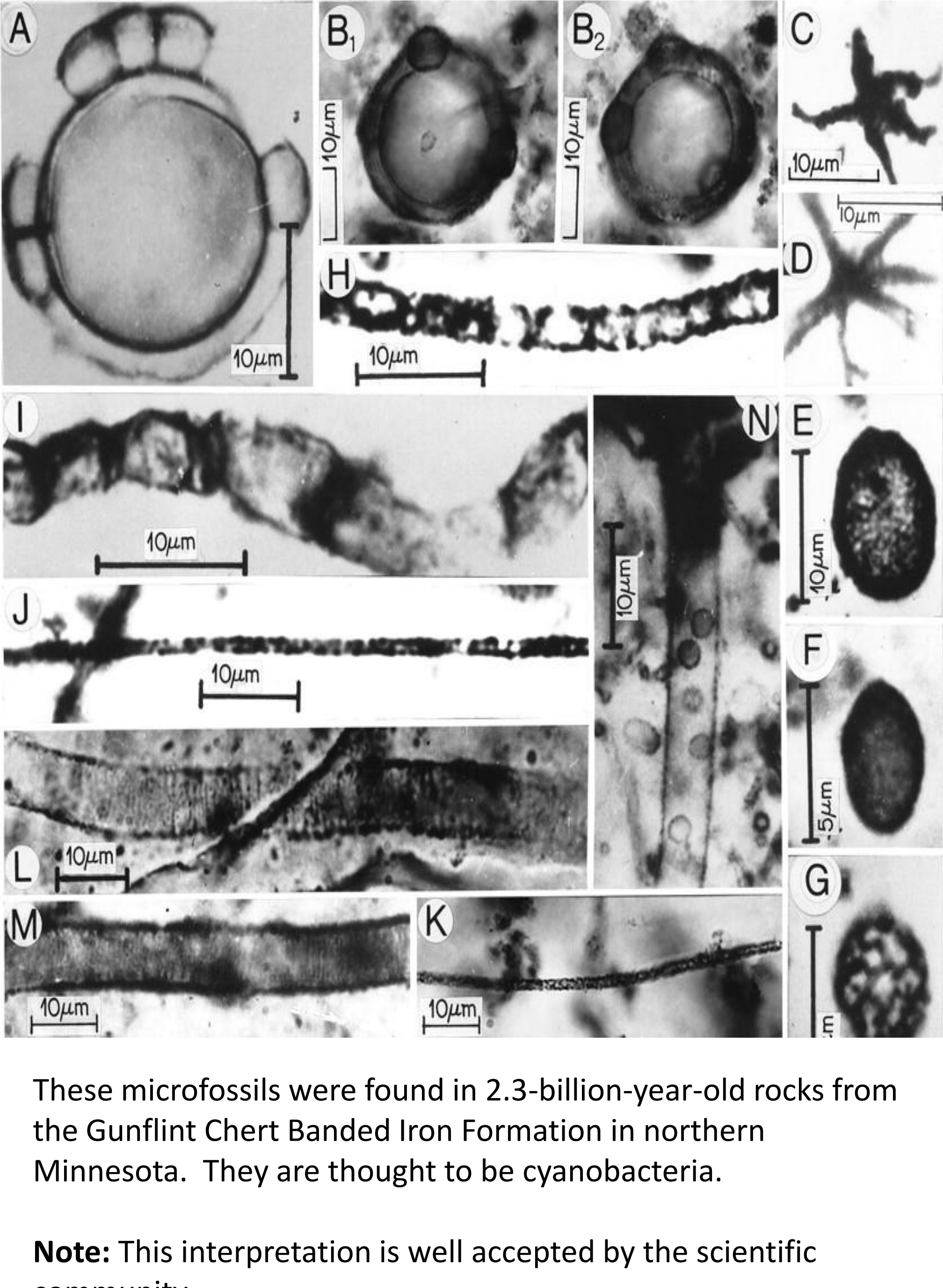
Reference: Berry et al. (2008) Oxidation state of iron in komatiitic melt inclusions indicates hot Archaean mantle. Nature 455: doi:10.1038/nature07377.



This is a 2.4 billion-year-old crystal of pyrite that was found in South Africa. One research team measured the sulfur isotopes inside the pyrite, and concluded that that sulfur isotope distribution could only have formed from interactions with a significant level of atmospheric oxygen.

Note: This interpretation is generally accepted by the scientific community

Reference: Lepot, Kevin; Karim Benzerara, Gordon E. Brown, Pascal Philippot (2008). "Microbially influenced formation of 2.7 billion-year-old stromatolites". Nature Geoscience 1: 118–21. doi:10.1038/ngeo107.



These microfossils were found in 2.3-billion-year-old rocks from the Gunflint Chert Banded Iron Formation in northern Minnesota. They are thought to be cyanobacteria.

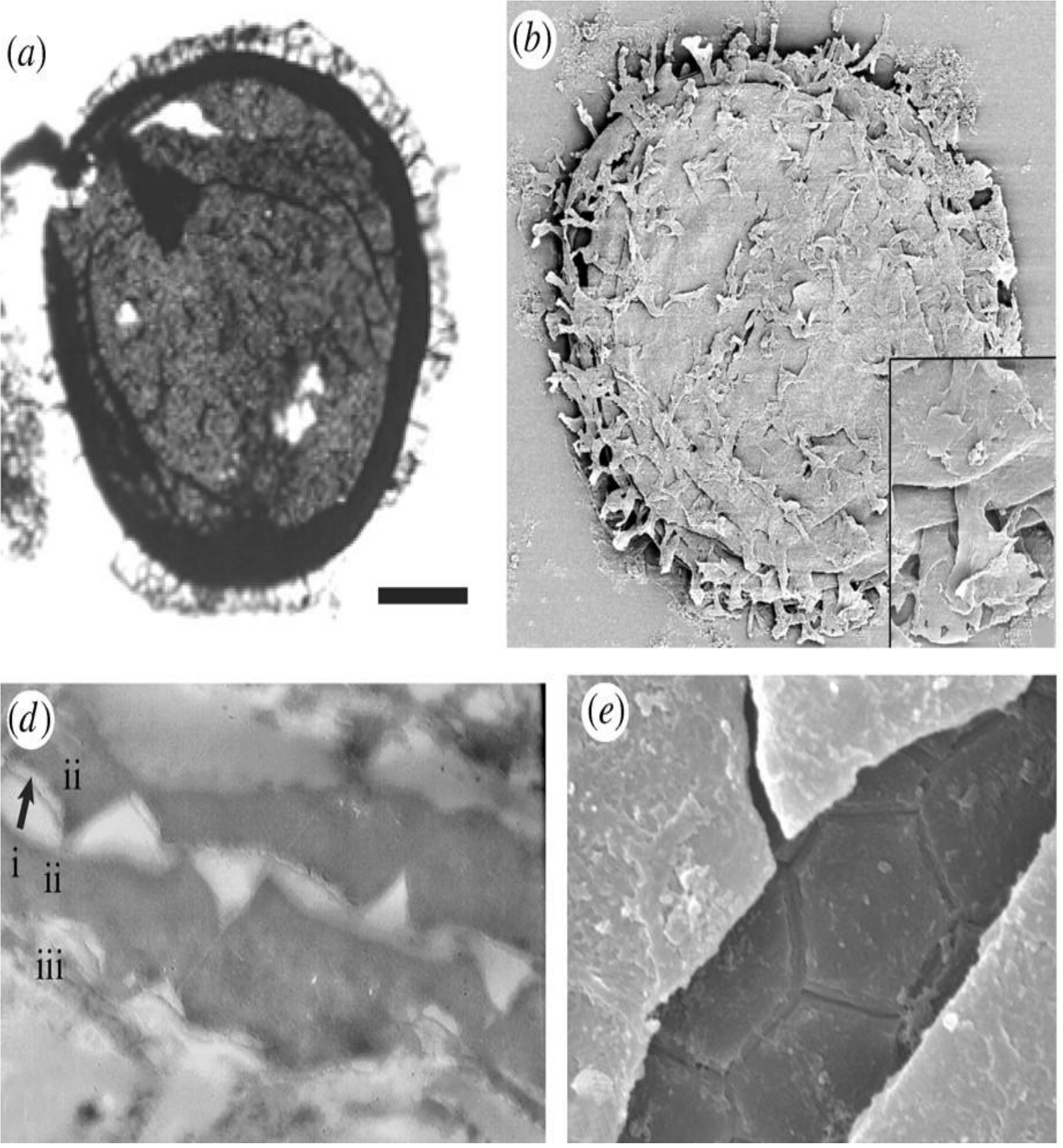
Note: This interpretation is well accepted by the scientific community

Reference: Barghoorn, E.S. and Tyler, S.A., 1965: Microorganisms from the Gunflint Chert. Science, vol. 147, p. 563-577.

These structures were found in 2.1-billion-year-old rocks from northern Minnesota. They are large (>1 cm) and so some researchers think they might be eukaryotic bacteria. They named the bacteria **Grypania.**

Note: This interpretation is still debated.

Reference: Han, T. M. & Runnegar, B. 1992. Megascopic eukaryotic algae from the 2.1-billion-year-old negaunee iron-formation, Michigan. Science, 257(5067): 232-235.



These structures were found in 1.6-billion-year-old rocks from China. They are usually interpreted as eurkaryotic cells.

Note: This interpretation is well accepted.

Reference: Yan Y, Zhu S 1992 Discovery of acanthomorphic acritarchs from the Baicaoping formation in Yongi, Shanxi, and its geological significance. Acta Palaeontol. Sin. 9, 267–282.

These 635-million-year-old rocks were found on the Arabian peninsula. One research team found organic compounds in the rock called sterane biomarkers: they are only produced by a certain ancient species of sponge: a complex animal.

Note: This work is still new, and so hasn't been debated to death yet, but it uses fairly standard analytical methods.

Reference: Love et al. (2009) Fossil steroids record the appearance of Demospongiae during the Cryogenian period. Nature 457: doi:10.1038/nature07673

Today, the major gases expelled by volcanoes are H_2O, CO_2, SO_2, CO, S_2, Cl_2, N_2, H_2.